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Conversion of polymer and perforated metallic residues into new value-added composite building materials

Mihails Lisicins[a]*, Vjaceslavs Lapkovskis[a], Andrew Shishkin[a], Viktors Mironovs[a], Vjaceslavs Zemcenkovs[b]

[a]*Riga Technical University, Faculty of Civil Engineering, Scientific Laboratory of Powder Materials, Azenes iela 16/20 – 331, Riga, LV-1048, Latvia*
[b]*Riga Technical University, Faculty of Transport and Mechanical Engineering, Institute of Aeronautics, Lomonosova iela 1a/1, Riga, LV-1019, Latvia*

Abstract

Construction is one area of human activity, where active and effective use of different types of materials is crucial, including a wide range of residual materials for new composite material development. In the current paper, a composite material based on combination of polymer and perforated steel waste materials is proposed. Comprehensive information about the raw material, its mechanical properties and geometrical shapes of perforated tapes obtained as industrial residues are shown. Examples of multi-layered composite material based on perforated steel band reinforced polymer and its applications are proposed.

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Keywords: residues; perforated steel tape; polypropylene; reinforcement; construction

1. Introduction

With increasing public awareness of environmental pollution and a continual increase of the cost of waste material disposal, industrial residual materials are becoming important raw materials for the manufacture of new materials and products [1].

* Corresponding author. Tel.: (+371) 26 042 451; fax: (+371) 67 089 067
E-mail address: mihails.lisicins@rtu.lv

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Significant groups of residual materials represent various types of polymer and metallic materials. Currently, the demand in metallic and polymeric materials as well as products made from such materials is increasing. Moreover, dynamics of metals demand is so active that by 2050 an increase of metal consumption up to 5 times comparing to 2010 is expected [2]. At the same time, recycling and reuse technologies of metallic materials are evolving. Based on studies conducted by the European Commission, the amount of reusable materials is very low [3] compared to the growing demand for metallic materials. Therefore, it is important to turn more public attention to development of new solutions for re-use and recycling of metallic materials.

Along with the boom in materials consumption and the continuous growth of the construction sector, the building construction industry will become one of the leading sectors of human activity by 2020 - about 70 % growth is expected compared to 2010 [1]. Thus, the construction industry can be one of the main drivers for metal and other residual materials recycling.

Perforated steel tape is a metallic residual material, which is mostly produced as a by-product of the small-size metal parts punching process. Among many European countries producing perforated materials, there are many types of perforated materials produced and processed by Latvian industry.

In the present work, a constructive composite material that can be effectively used in construction is presented. The composite material is produced by combining two types of residual materials − a polymer material and perforated steel tape.

Nomenclature

F force
GOST (Russian: ГОСТ) refers to a set of technical standards maintained by the Euro-Asian Council for Standardization, Metrology and Certification (EASC)
IMS Institute of Materials and Structures (Riga Technical University, Faculty of Civil Engineering)
PST Perforated steel tape

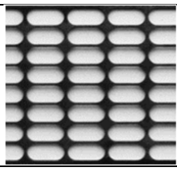
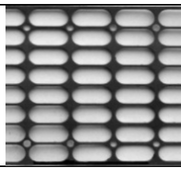
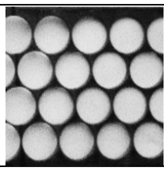
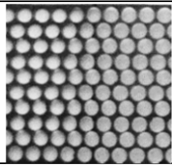
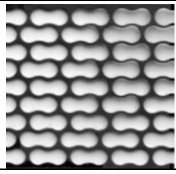
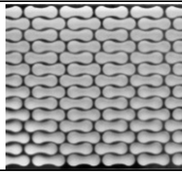
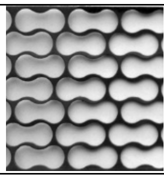
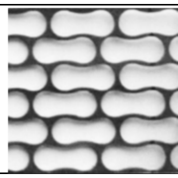
2. Materials and methods

2.1. Perforated steel residues

Perforated steel tape used in experiments is a residual material obtained from the punching process during the manufacturing of driving chain elements. Suggested materials are characterized by good mechanical properties (Table 1) and moderate costs (Table 2), which is about 1/3 of the price of solid steel material. There are many chain manufacturers where such steel materials are employed, for instance, in Novosibirsk (Russia), Dnepropetrovsk (Ukraine), Rexnord Kette and Rohloff Chain (Germany) driving chain factories. In the Latvian market, the driving chain company JSC "DITTON Driving Chain Factory" is producing about 500 tonnes per year of different types of perforated steel bands [4]. Traditionally, perforated steel waste is subject to recasting, as a recycling technique [5]. However, this approach leads to additional energy consumption and to slag waste formation.

The variety of the geometrical and mechanical properties in perforated steel tape residue, offers good perspectives to further reuse perforated steel waste for new materials development. Available perforated steel waste differs by tape width, thickness, perforations gap shapes and sizes, as well as in terms of steel grades. Main technological characteristics of the perforated steel tape obtained from the tests of actual materials at the Riga Technical University (IMS laboratory) are shown in Table 1.

Table 1. Types and technical characteristics of perforated steel residues in JSC "DITTON Driving Chain Factory"

Type of residue				
Designation	PST-1	PST-2	PST-3	PST-4
Mark of steel	50-T-C-H	50-T-C-H	08пс-ОМ-Т-2-К	08пс-ОМ-Т-2-К
Standard	GOST 2284-79	GOST 2284-79	GOST 503-81	GOST 503-81
Thickness, mm	1.20	1.20	1.50	1.25
Width, mm	80	80	80	93
Permeable area, %	70.50	71.40	69.10	66.97
Effective cross-sectional area, mm^2	14.44	14.44	25.13	16.14
Tensile load bearing capacity, N	13478.70	12680.42	5539.86	4108.27
Tensile strength, N/mm^2	933.43	878.84	220.65	318.22
Displacement, mm	2.43	2.87	6.54	3.27
Strain, %	1.44	1.55	3.93	1.78
Type of residue				
Designation	PST-5	PST-6	PST-7	PST-8
Mark of steel	50-T-C-H	08пс-ОМ-Т-2-К	50-T-C-H	50-T-C-H
Standard	GOST 2284-79	GOST 503-81	GOST 2284-79	GOST 2284-79
Thickness, mm	1.20	1.00	1.50	1.75
Width, mm	80	110	90	75
Permeable area, %	72.25	76.12	75.32	69.97
Effective cross-sectional area, mm^2	18.12	19.70	26.43	28.45
Tensile load bearing capacity, N	9314.00	5889.05	10052.61	12126.15
Tensile strength, N/mm^2	511.56	298.94	406.81	416.05
Displacement, mm	2.50	2.33	2.25	1.91
Strain, %	1.35	1.26	1.21	0.90

Waste material re-use efficiency is strongly linked to their geometrical characteristics, as well as to their physical and mechanical properties. Geometrical shape and physical properties are of importance for development of decorative and non-structural materials and components. Meanwhile, mechanical properties are vital for load-bearing elements and construction manufacturing. The market value of perforated steel waste is equal to scrap metal values, thus new solutions for material re-use in construction may significantly save raw materials and final product costs. Some economic indicators of selected perforated steel tapes are shown in Table 2.

Table 2. Economic characteristics of perforated steel residues in JSC "DITTON Driving Chain Factory"

Type of residue	Price for 1t of tape, €	Price for 1 m^3 of tape, €	Price for 1 m of tape, €	Price for tensile strength of tape, €/100MPa	Price for load bearing capacity of tape, €/tF
LPM-1	190.00	2303.95	0.042	0.004	0.031
LPM-2	190.00	2233.66	0.041	0.005	0.032
LPM-3	190.00	2596.00	0.059	0.027	0.108
LPM-4	190.00	2592.86	0.057	0.018	0.139
LPM-5	190.00	2167.28	0.040	0.008	0.043
LPM-6	190.00	1874.58	0.039	0.013	0.066
LPM-7	190.00	1927.51	0.049	0.012	0.049
LPM-8	190.00	2345.34	0.058	0.014	0.048

2.2. Polymer residues

In the European Union, polymer demand is ensured mainly by the packaging industry, construction, automotive industries, electrical and electronics, and some other branches of industry (Fig. 1a). There are different types of plastic material with a variety of grades, which deliver specific properties for each application (Fig. 1b). The most common types of polymers used in the EU are polyethylene and polypropylene, amounting to almost 55 % of polymers used in various technological processes [6].

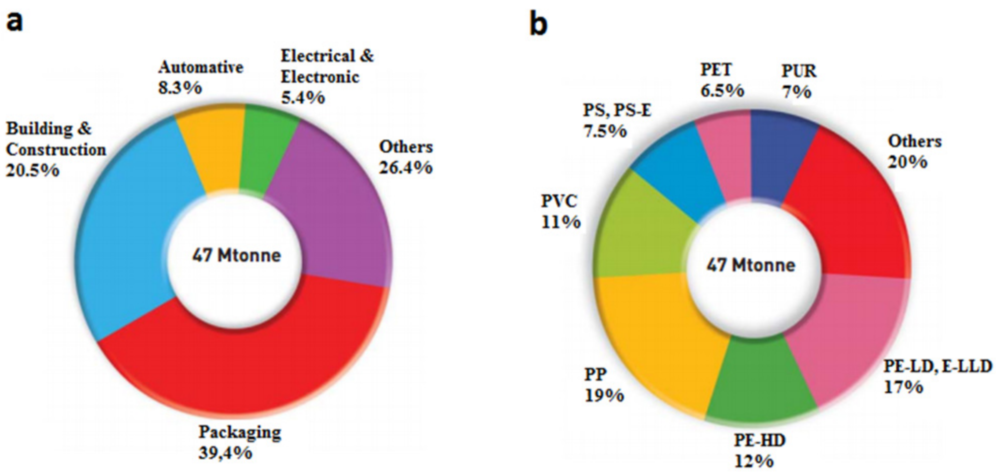


Fig. 1. (a) European plastics demand by segment 2011; (b) European plastics demand by resin type 2011 (PE-LD – polyethylene including low density, PE-LLD – polyethylene including linear low density, PE-HD – polyethylene including high density, PP – polypropylene, PVC – polyvinyl chloride, PS – polystyrene solid, PS-E – polystyrene expandable, PET – polyethylene terephthalate, PUR - polyurethane)

Polyethylene and polypropylene wastes have a very long period of decomposition which is why we try to pay more attention to polyethylene and polypropylene waste materials re-use. Polymer material residues can be combined with perforated steel material wastes, creating new composite materials suitable for construction industry. Polyethylene and polypropylene possess good weldability that allows fast and convenient materials to join for different types of structures. In the present study, we have used a polypropylene as a raw material, the properties of which are presented in Table 3.

Table 3. Technical characteristics of polypropylene used in experimental tests

Characteristic	Value
Density, g/cm^3	0.91
Modulus of elasticity, N/mm^2	1300
Tensile strength, N/mm^2	32.00
Breaking extension, %	>50
Melting point, °C	162−167

2.3. Methods for producing composite material from polymer and perforated metallic residues

Joining of metallic and polymer materials is a difficult issue [7, 8]. Perforated steel band has an advantage thanks to perforation slots, allowing the melted polymer to flow through the openings and ensuring mutual adhesion. There are three possible techniques for incorporation of perforated steel band into polymer matrix:

- Hot polymer casting;
- Polymer mass extrusion through the matrix, incorporating a steel tape;
- Hot pressing method (Fig.2).

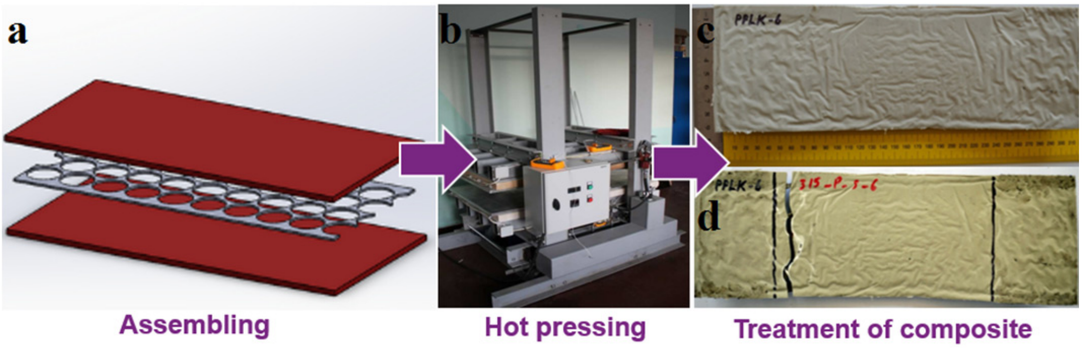


Fig. 2. Producing of steel reinforced polymer composite: (a) Structure of composite; (b) Hot press; (c) Finished composite; (d) Sample testing.

In our experimental case, the composite material was produced by means of a hot pressing process. Initially, metal parts made of steel LMP-4 sample (Table 1) with overall dimensions 1.5 × 80 × 300 mm and polypropylene sheets with overall dimensions 3.0 × 90 × 310 were prepared. The pressing equipment was set to heat up to 210 °C, providing the press plate temperature up to 180 °C and ensuring complete polypropylene melting. Raw materials were stacked together providing a polypropylene-perforated tape-polypropylene multilayer structure (Fig. 2a). After pressing (Fig. 2b) for the purpose of tensile strength trials on INSTRON 8802, the samples were trimmed to dimensions 310 × 90 × 6.30 mm (Fig 2c). Mechanical characteristics of obtained polymer-metal composite samples are shown in Table 4.

Table 4. Mean values of mechanical characteristics of the polymer-metal composite samples

Characteristic	Mean value
Maximum axial tensile load, kN	21.64
Tensile stress, N/mm^2	39.28
Strain, %	4.14
Elastic modulus, GPa	3.38

3. Application possibilities of new value-added composite building material

3.1. Application for polymer profiles reinforcement

One of the most promising applications of obtained composite material is new reinforced materials design (Fig. 3a), and reinforcement of existing polymer structures (Fig. 3b).

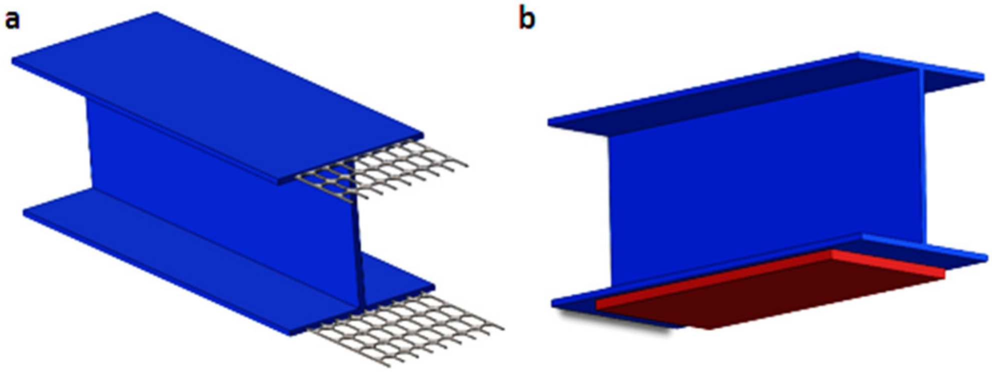


Fig. 3. (a) Polymer I-beam reinforced by perforated steel plates; (b) Lower flange of polymer I-beam strengthened with reinforced composite plate based on perforated steel plate and polymer matrix.

For example, glass fibre composite profiles possess excellent tensile and compressive strength properties, but their great disadvantage is low modulus of elasticity, which in most cases is between 17–22 MPa in the longitudinal direction, and from 5-16 MPa in the transversal direction of the material [9]. Low stiffness due to deflection is much larger compared to metal profiles, thus for constructive conditions it is necessary to increase several times the cross-section of the designed element. There have been attempts to strengthen their profiles with non-perforated steel sheets, but in this case it is technologically difficult to provide a sufficient adhesion of composite material to solid metallic element. Meanwhile, introducing perforated metal tape into polymer materials (profile), leads to significant increase of polymer part stiffness. Moreover, perforation slots provide greater mutual adhesion of the polymer during solidification. It is also possible to bind composite polymer parts by welding (Fig. 3a). Additionally, polymer layer provides protection against corrosion of the steel band, ensuring the quality of welded products.

3.2. Application for electromagnetic shielding solution

Perforated steel band structures can be employed for the purpose of electromagnetic shielding [10] for electric machines and in working environments (Fig. 4a). Multilayer perforated steel elements with polymer lamination may increase the operational efficiency of the shielding screen, protect perforated steel against corrosion, as well as make them more visually appealing (Fig. 4b). The relationship between magnetic field strength and the distance between the measuring probe and the source of the magnetic field is shown in Fig. 4c.

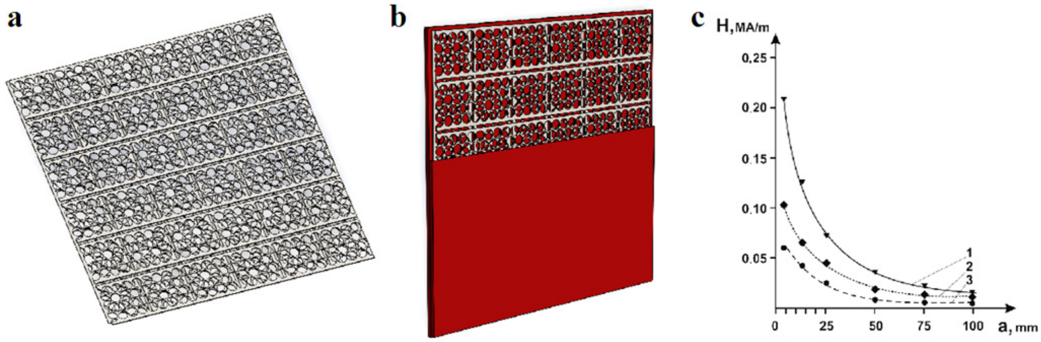


Fig. 4. (a) Shielding screen of cross-spaced perforated steel plates; (b) Shielding screen in polymer matrix; (c) Dumping curve of magnetic field strength with distance *a (1 - without shielding screen, 2 - with single layer welded shield, 3 - with dual layer interlaced shield)*

4. Conclusion

In the present study, the processing of industrial waste for new composite materials development is outlined. A new composite material made of residues of polypropylene reinforced by perforated steel band is introduced. During the experiments, it was found that linkage between metal and a polymer component is weak due to an insufficient adhesion between components. However, steel band slots filled with polypropylene ensures tight bounding of layers, providing better functionality and mechanical properties of the obtained composite material. The obtained composite material can be employed in new reinforced materials design, or for reinforcement of existing polymer structures, as well as for electromagnetic shielding [10] screens for electrical machines isolation purpose in working environments.

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